MEDIUM-β SUPERCONDUCTING ACCELERATING STRUCTURES

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Jefferson Lab

Spoke Resonator Workshop

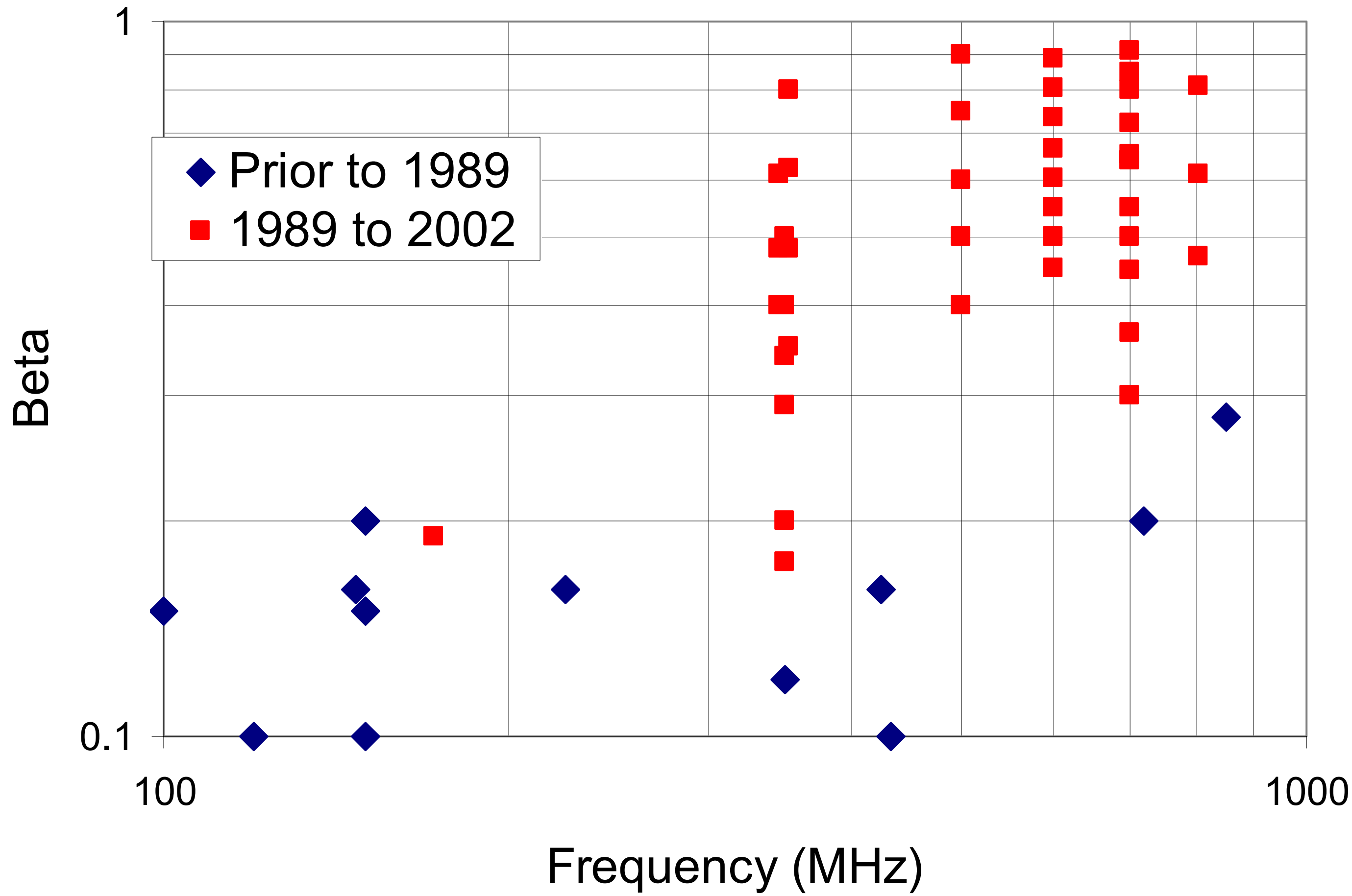
Los Alamos

7-8 October 2002

Outline

- Historical background
- Basic geometries
- Survey of properties
- Summary

β<1 Superconducting Structures – 2002



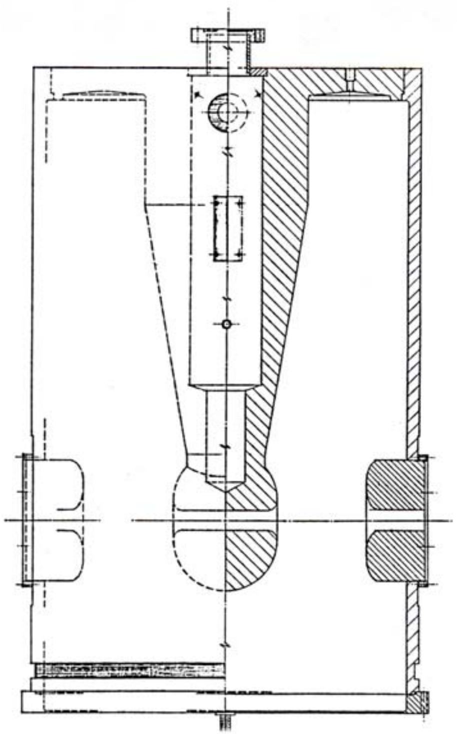
Basic Structure Geometries

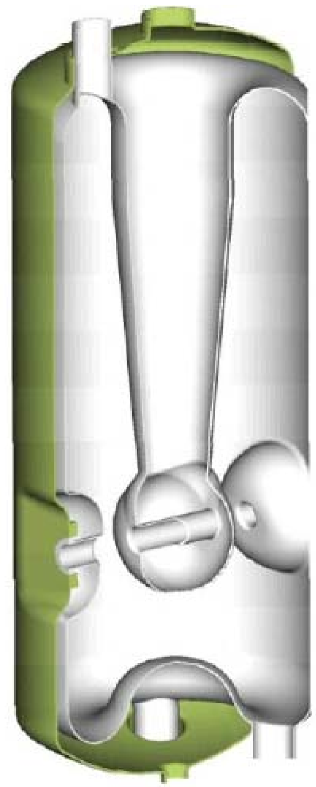
- **Resonant Transmission Lines**
  - λ/4
    - Quarter-wave
    - Split-ring
    - Twin quarter-wave
    - Lollipop
  - λ/2
    - Coaxial half-wave
    - Spoke
    - H-types

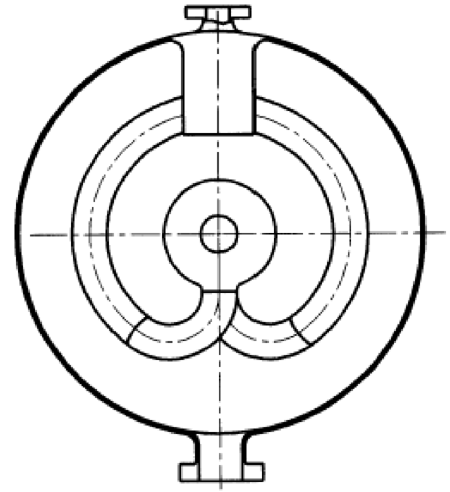
- **TM**
  - Elliptical
  - Reentrant

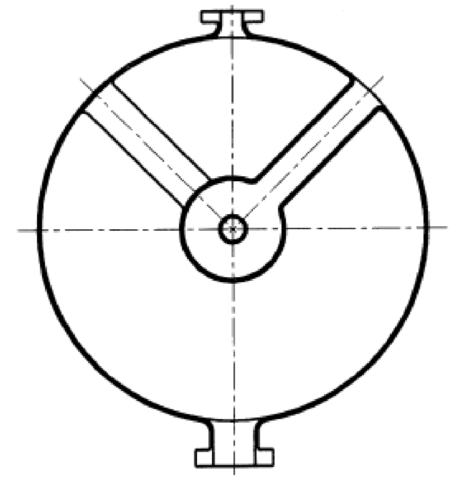
- **Other**
  - Alvarez
  - Slotted-iris

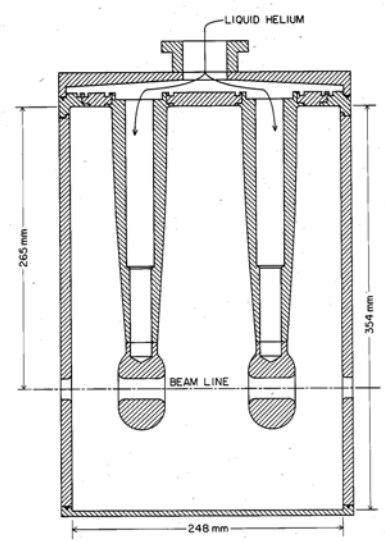
λ/4 Resonant Lines

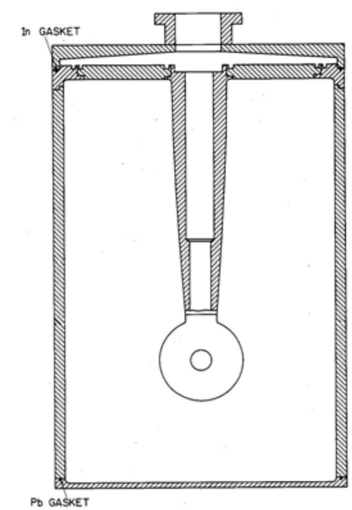




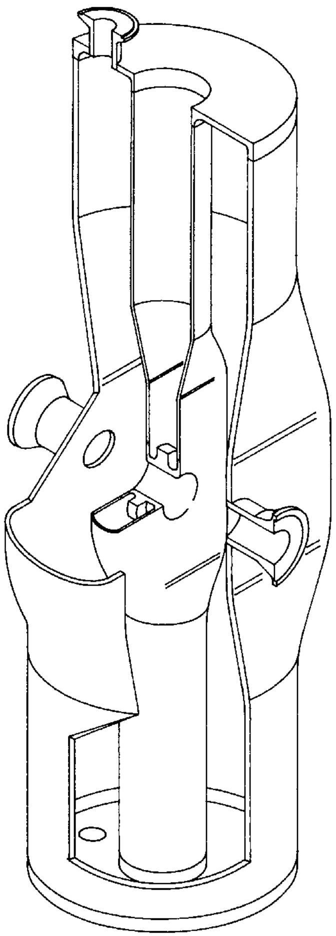


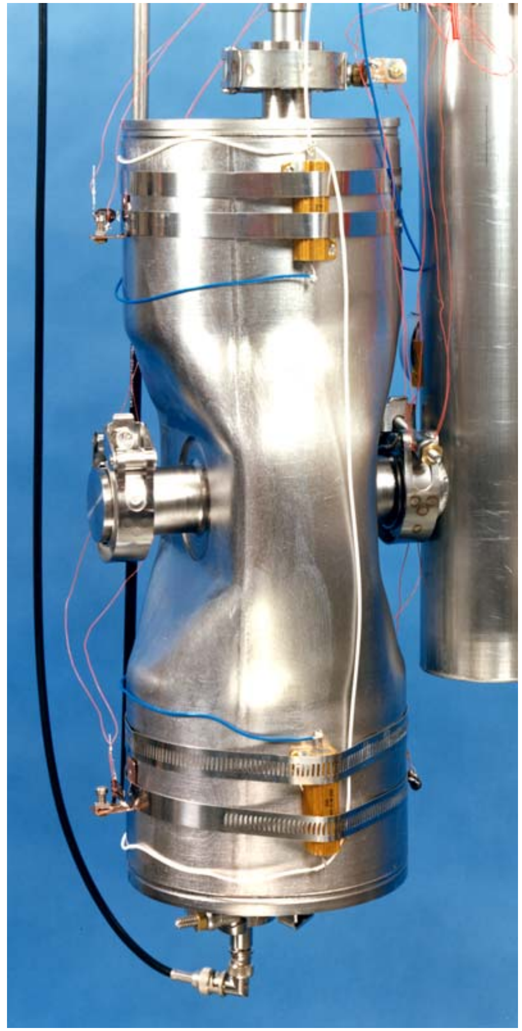


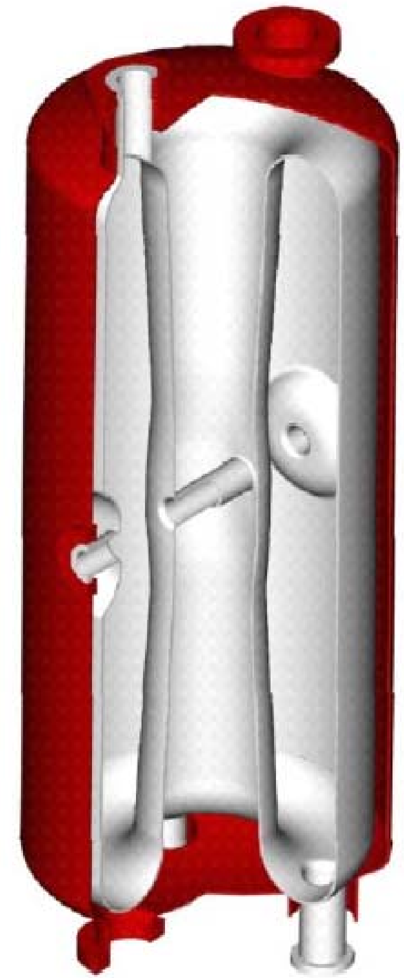




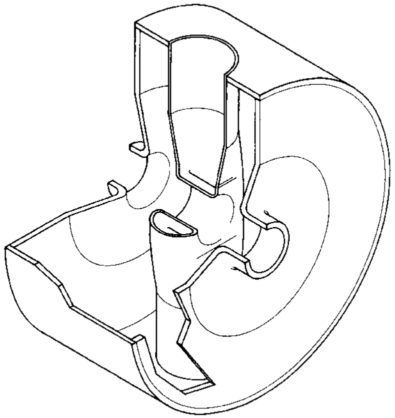
λ/2 Resonant Lines

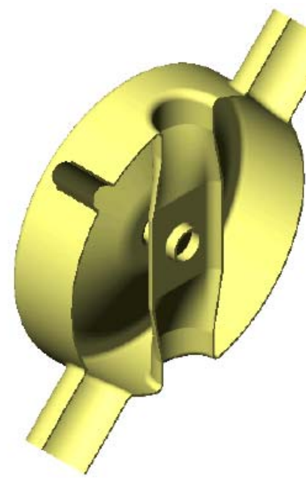


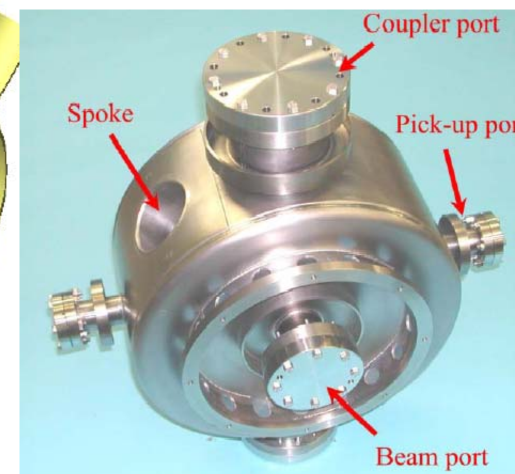




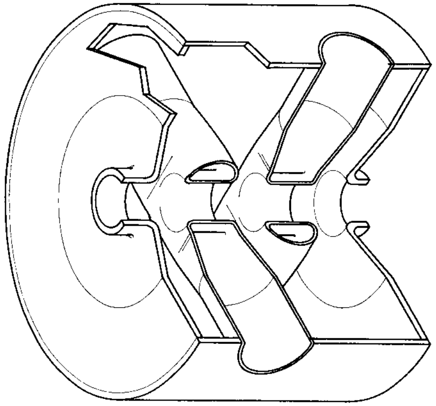
λ/2 Resonant Lines – Single-Spoke

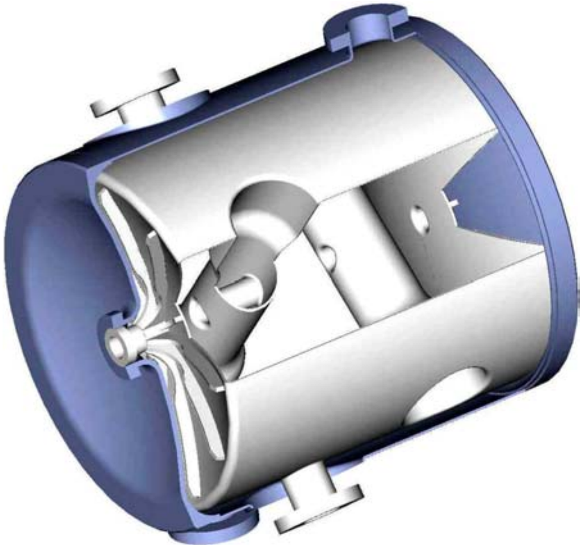


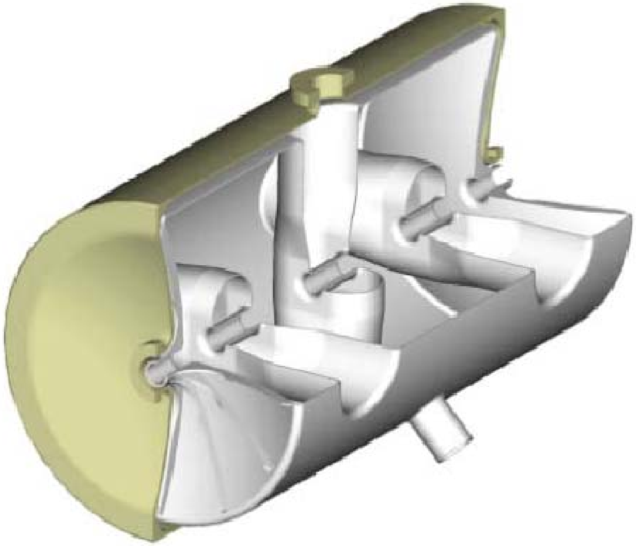




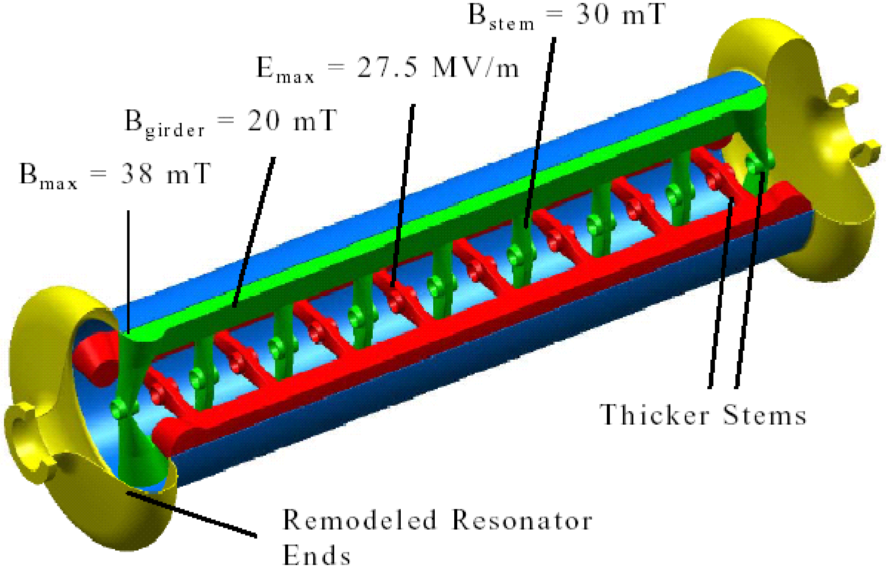
λ/2 Resonant Lines – Double and Triple-Spoke



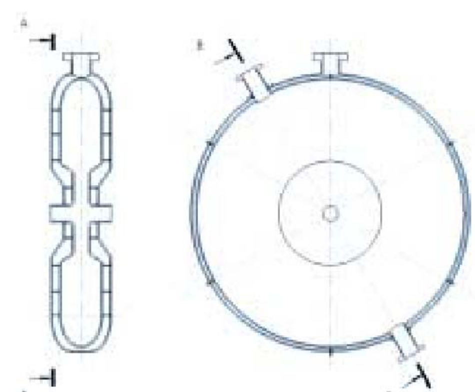




λ/2 Resonant Lines – Multi-Spoke



TM Modes

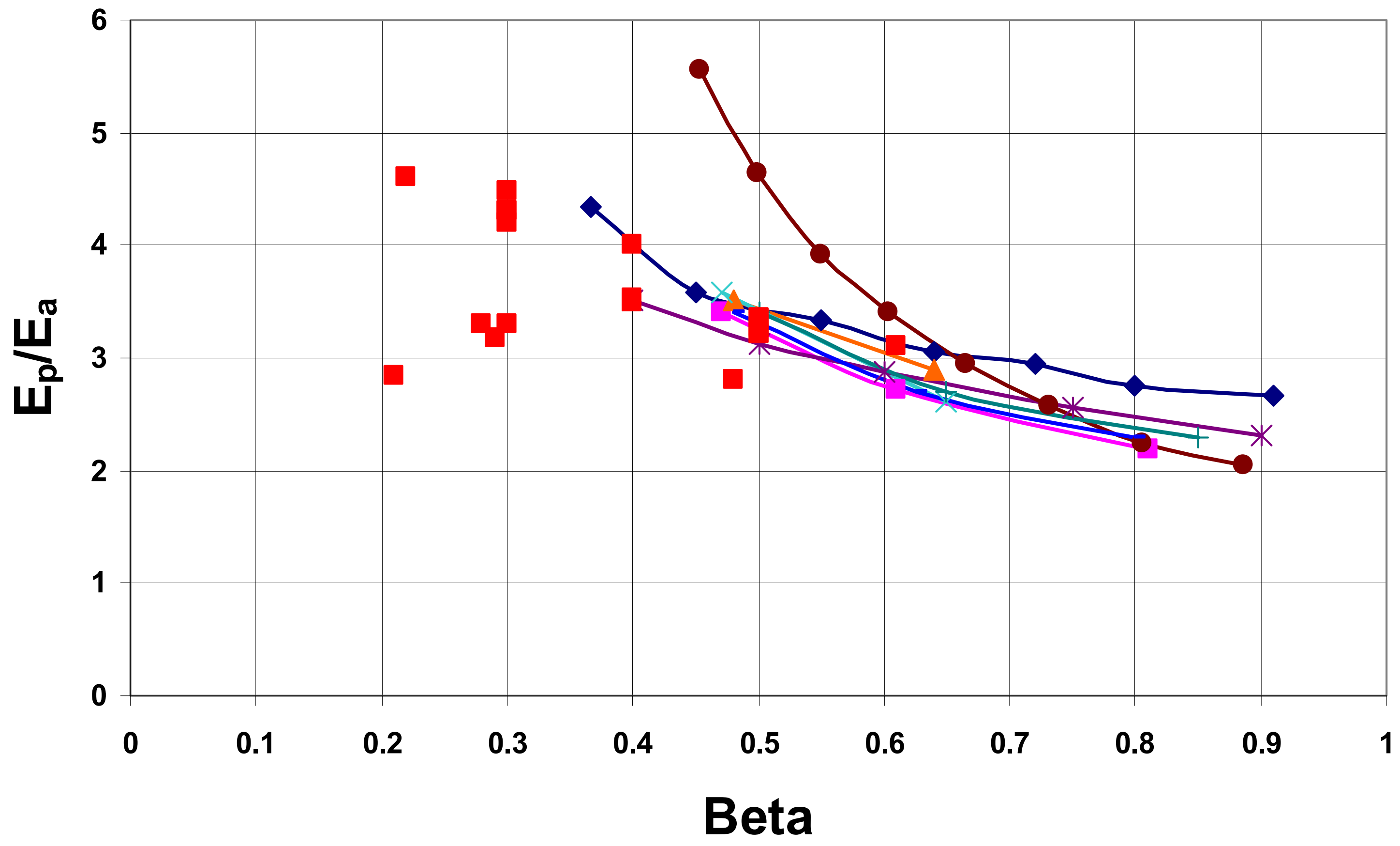


Surface Electric Field

- TM_{010} elliptical structures
  - $E_p/E_a \sim 2$ for $\beta = 1$
  - Increases slowly as β decreases
- $\lambda/2$ structures:
  - Sensitive to geometrical design
  - Electrostatic model of an "shaped geometry" gives $E_p/E_a \sim 3.3$, independent of β

Surface Electric Field

- Lines: Elliptical Squares: Spoke



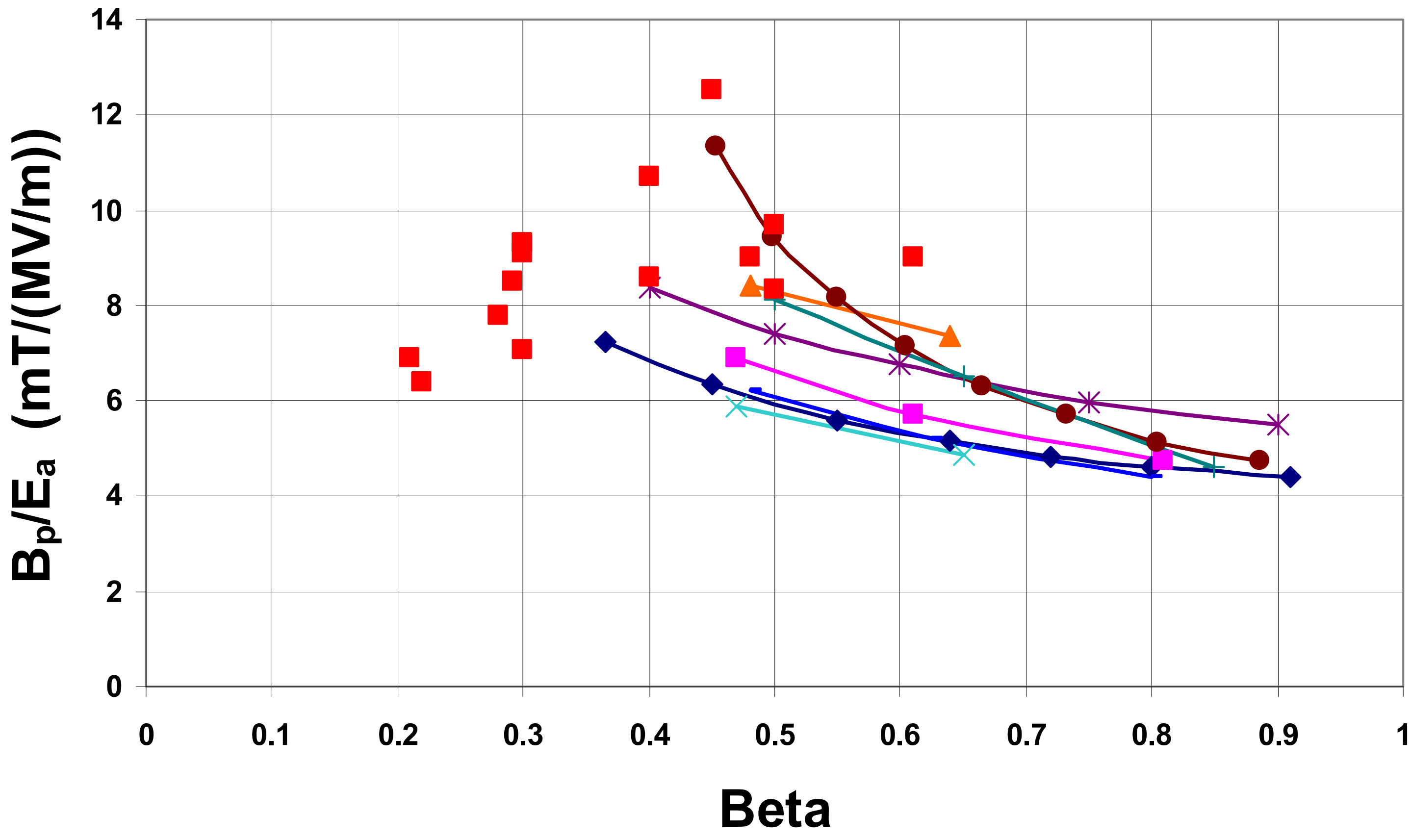
Surface Magnetic Field

- TM_{010} elliptical cavities:
  - $B/E_a \sim 4$ mT/(MV/m) for β=1
  - Increases slowly as β decreases

- $\lambda/2$ structures:
  - Sensitive to geometrical design
  - Transmission line model gives $B/E_a \sim 8$ mT/(MV/m), independent of β

Surface Magnetic Field

- Lines: Elliptical Squares: Spoke



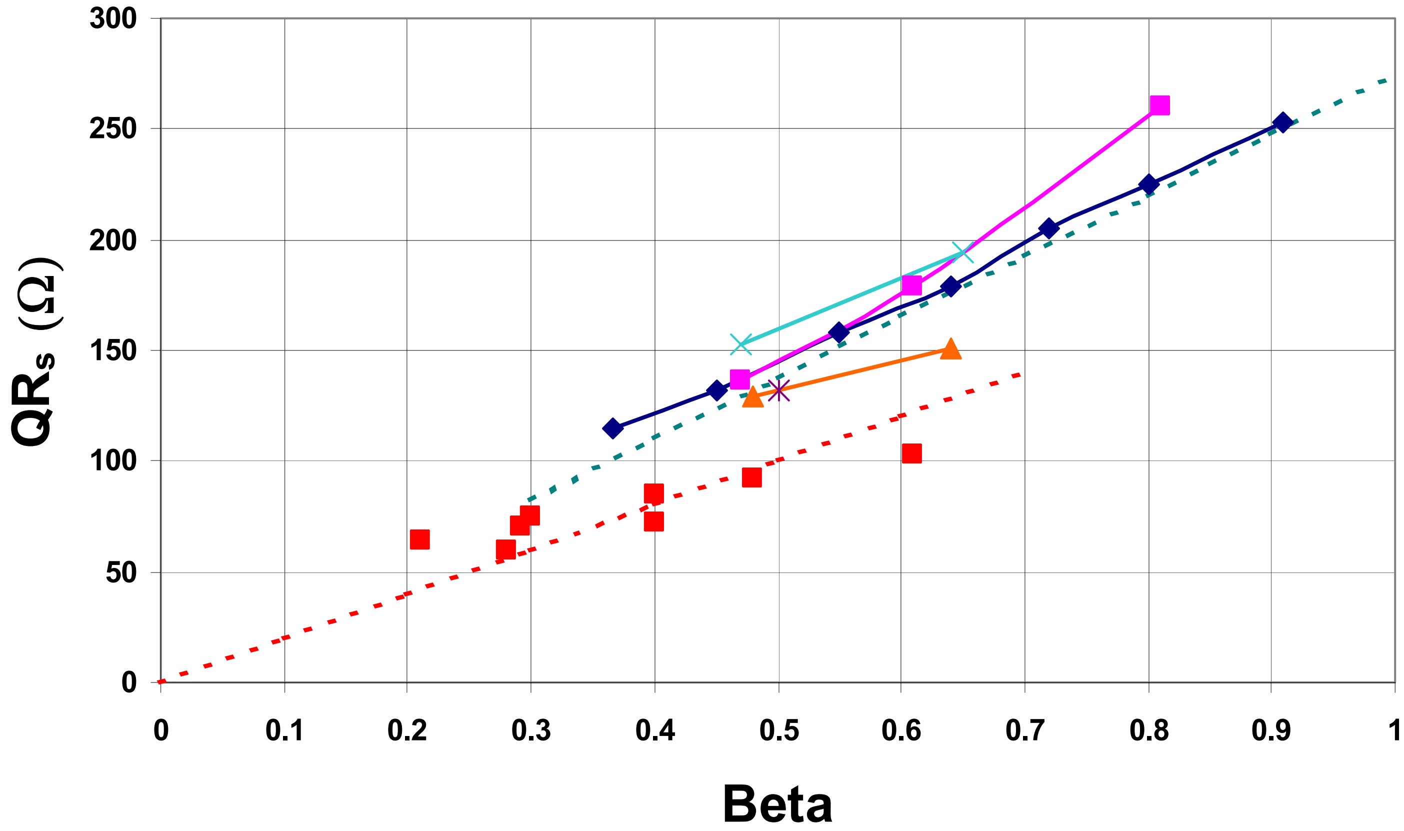
Geometrical Factor (QR_s)

- TM_{010} elliptical cavities:
  - Simple scaling: $QR_s \sim 275\ \beta\ \ (\Omega)$

- $\lambda/2$ structures:
  - Transmission line model: $QR_s \sim 200\ \beta\ \ (\Omega)$

Geometrical Factor (QR_s)

- Lines: Elliptical Squares: Spoke



R_{sh}/Q per cell or loading element

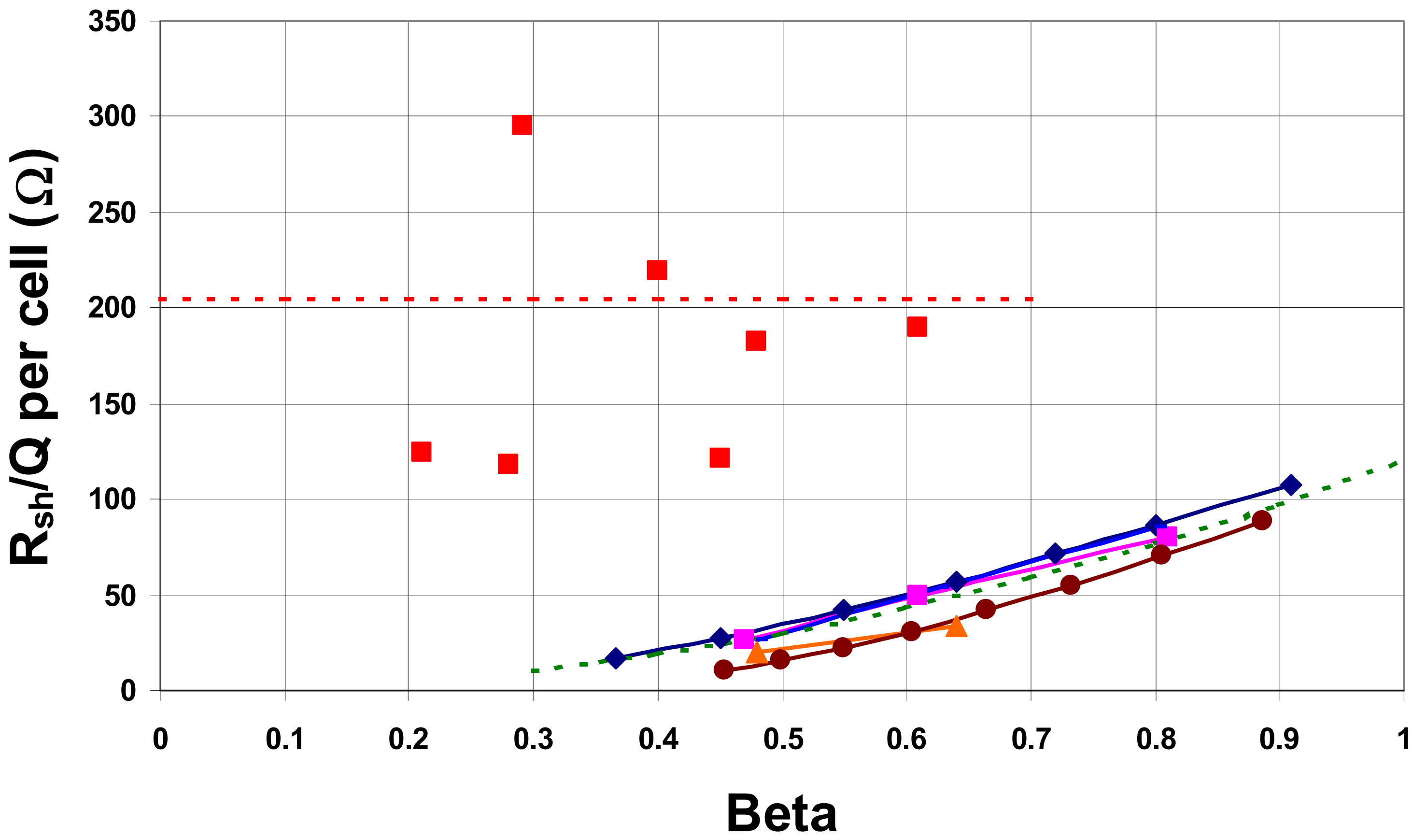
- $R_{sh} = V^2/P$

- TM_{010} elliptical cavities:
  - Simple-minded argument, ignoring effect of beam line aperture, gives : $R_{sh}/Q \propto \beta$
  - When cavity length becomes comparable to beam line aperture : $R_{sh}/Q \propto \beta^2$
  - $R_{sh}/Q \approx 120\ \beta^2 \quad (\Omega)$

- $\lambda/2$ structures:
  - Transmission line model gives: $R_{sh}/Q \approx 205\ \Omega$
  - Independent of β

R_{sh}/Q per cell or loading element

Lines: Elliptical Squares: Spoke



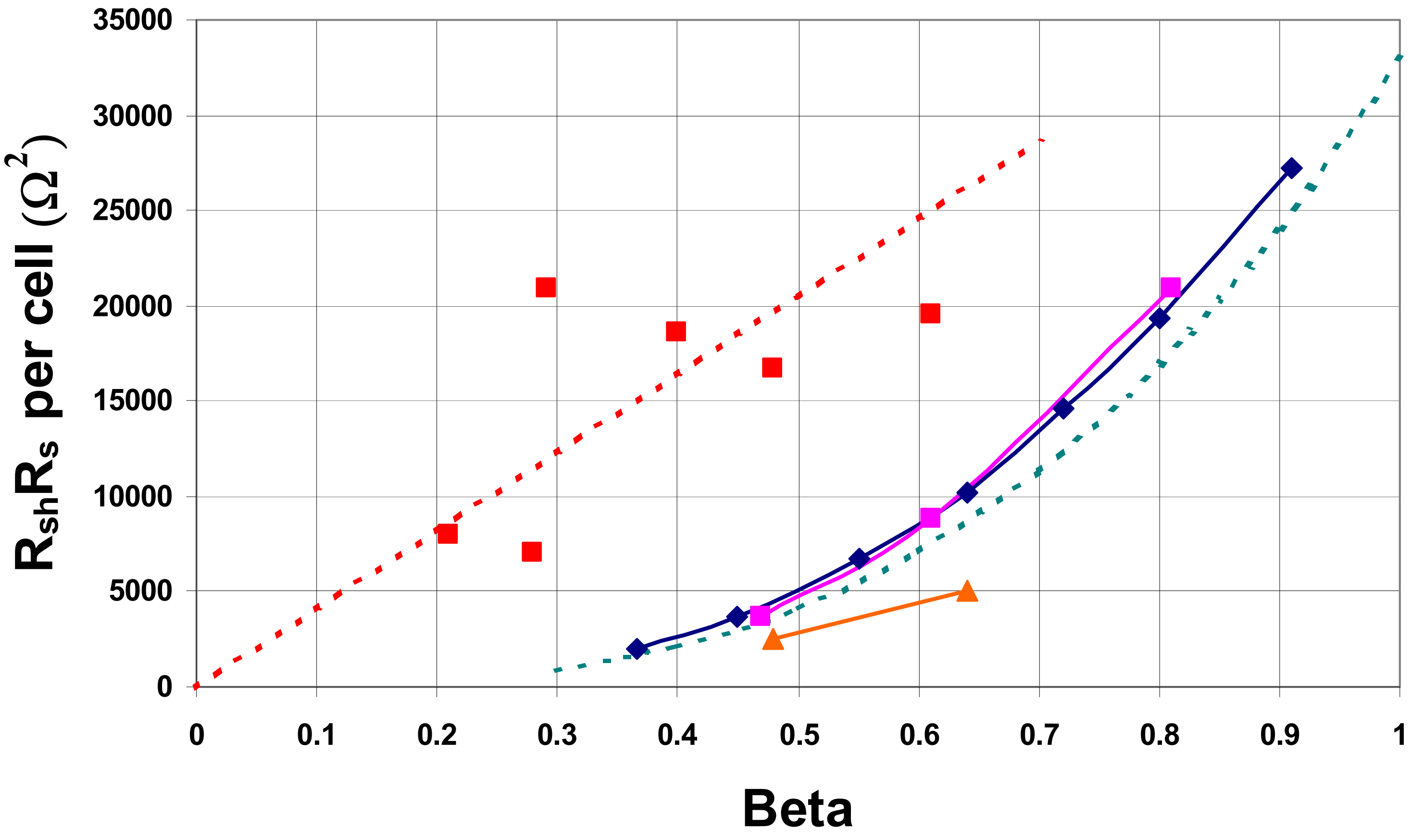
Shunt Impedance R_{sh}
(R_{sh}/Q QR_s per cell or loading element)

- TM_{010} elliptical cavities:
  - $R_{sh}\ R_s \sim 33000\ \beta^3 \quad (\Omega^2)$

- $\lambda/2$ structures:
  - $R_{sh}\ R_s \sim 40000\ \beta \quad (\Omega^2)$

Shunt Impedance R_{sh}
(R_{sh}/Q QR_s per cell or loading element)

- Lines: Elliptical Squares: Spoke



Energy Content per Cell or Loading Element

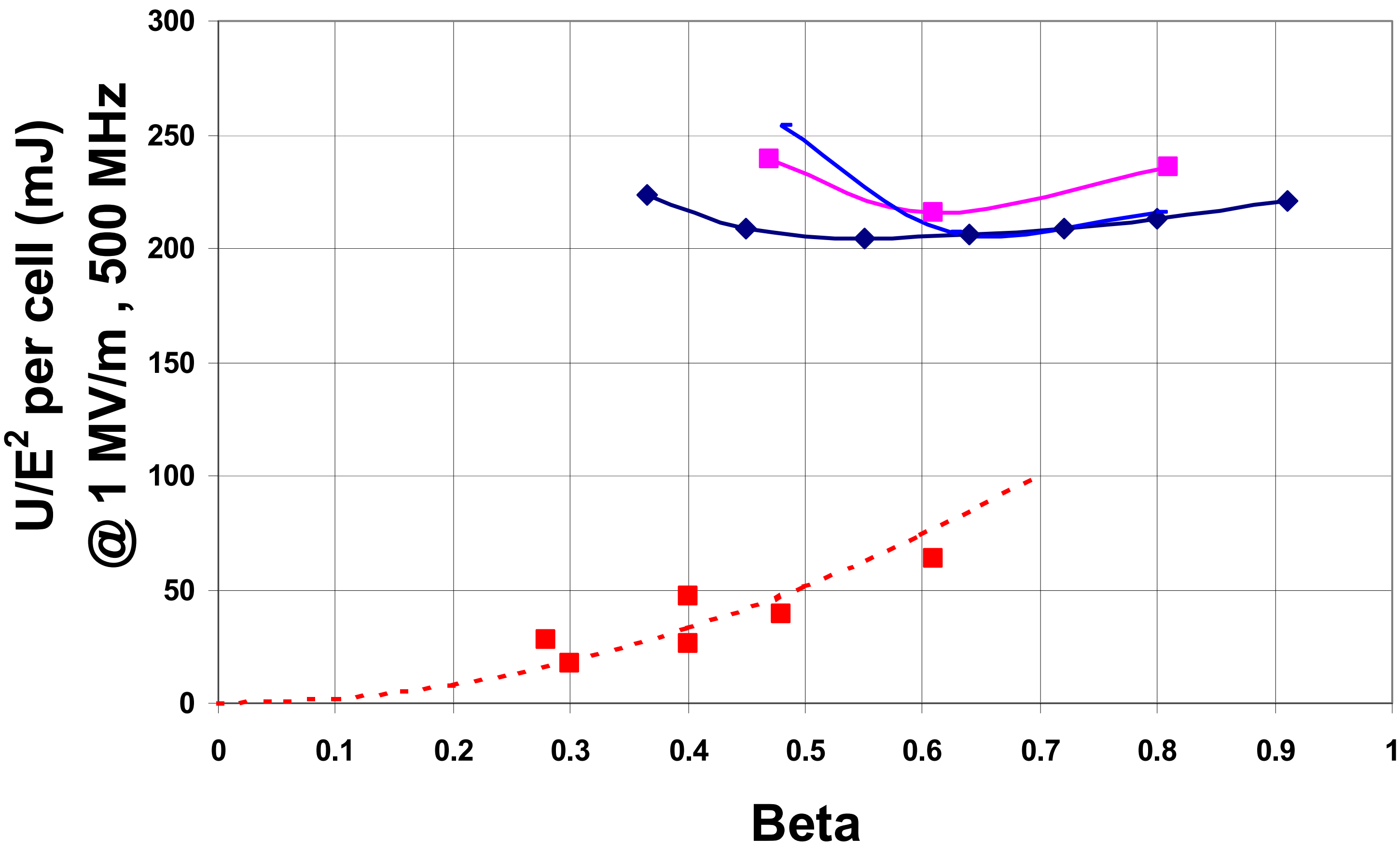
Proportional to $E^2\lambda^3$

At 1 MV/m, normalized to 500 MHz:

- TM_{010} elliptical cavities:
  - Simple-minded model gives $U/E^2 \propto \beta$
  - In practice: $U/E^2 \sim 200\text{-}250$ mJ
  - Independent of β (seems to increase when $\beta < 0.5 - 0.6$)

- $\lambda/2$ structures:
  - Sensitive to geometrical design
  - Transmission line model gives $U/E^2 \sim 200\ \beta^2$ (mJ)

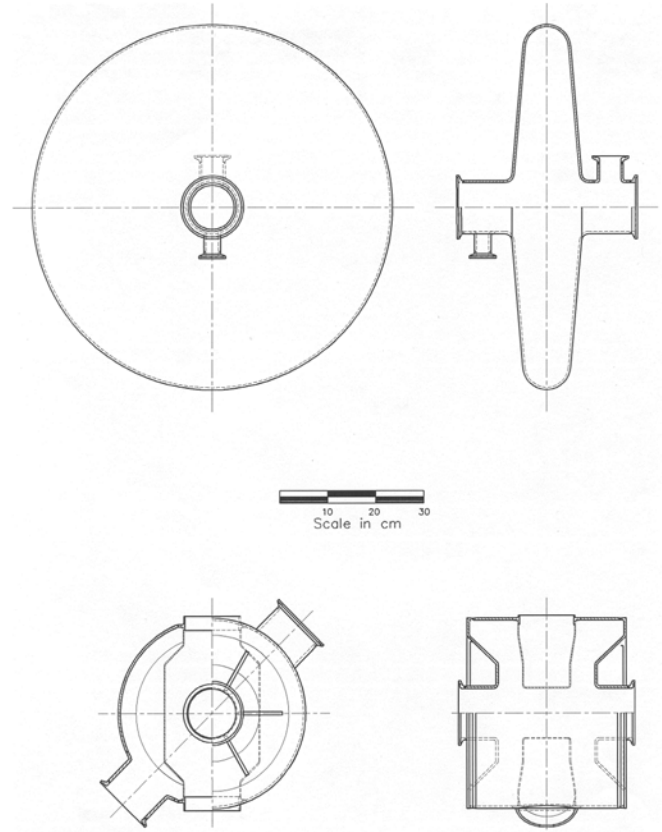
Energy Content per Cell or Loading Element



Size & Cell-to-Cell Coupling

- TM_{010} Structures
  $\varnothing \sim$ 0.88 – 0.92 λ
  Coupling ~ 2%

- $\lambda/2$ Structures
  $\varnothing \sim$ 0.46 – 0.51 λ
  Coupling ~ 20 - 30%



Example : 350 MHz, β= 0.45

Multipacting

- TM_{010} elliptical structures
  - Can reasonably be modeled and predicted/avoided
  - Modeling tools exist

- $\lambda/2$ Structures
  - Much more difficult to model
  - Reliable modeling tools do not exist
  - Multipacting “always” occurs
  - “Never” a show stopper

TM Structures – Positive Features

- Geometrically simple
- Familiar
- Large knowledge base
- Good modeling tools
- Low surface fields at high β
- Small number of degrees of freedom

λ/2 Structures – Positive Features

- Compact, small size
- High shunt impedance
- Robust, stable field profile (high cell-to-cell coupling)
- Mechanically stable, rigid (low Lorentz coefficient, microphonics)
- Small energy content
- Low surface fields at low β
- Large number of degrees of freedom

What Next?

- How high in β can spoke cavities go?
- What are their high-order modes properties?
  - Spectrum
  - Impedances
  - Beam stability issues
- Is there a place for spoke cavities in high-β high-current applications?
  - FELs, ERLs
  - Higher order modes extraction